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Improved light harvesting in N719 sensitized nanocrystalline TiO_2 solar cells with Coumarin 6 dye

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Abstract

Dye-sensitized solar cells (DSSCs) are a promising alternative to conventional semiconductor solar cells due to their ease of fabrication and low manufacturing cost. Ru-based dyes, particularly N719, are the typical dye for DSSC applications. However, N719-based DSSCs have weak absorbance at a wavelength around 440 nm. In this work, we aimed to improve light absorption of the N719-based DSSCs by adding a luminescent dye, Coumarin 6 (C6), into an electrolyte. C6 dye were chosen as it has an absoption and luminescence spectrum complementary to that of N719. The absorption and luminescence spectra of the C6 solution with different dye concentrations, ranging from 1 – 25 μM, were investigated in order to find the optimum concentration that is suitbale for the DSSC applications. Moreover, N719 based DSSCs with and without C6 added were fabricated and experimentaly compared. The measurement results show that the N719-based DSSC with C6 dye has the improvement in both short circuit current and device efficiency.

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Keywords: Dye sensitized solar cells; Coumarin 6; N719.

1. Introduction

A dye sensitized solar cell (DSSC) has received considerable attention from researchers worldwide as it has a simple structure, ease of fabrication and low manufacturing cost [1, 2]. Although the power conversion efficiency of the DSSC has been currently improved to 11% [3, 4], improvement of the conversion efficiency and the long-term

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stability of DSSCs remains a challenge. Typically, ruthenium complexes dyes such as N719, Z907, N3 and N749 dyes are used as the sensitizer in DSSCs. These dyes have two absorption peaks in the UV/Visible region and a valley between them [5, 6]. To improve the poor absorption in this region, the spectrum down-conversion (SDC) method can be employed to convert the solar spectrum into frequencies better fitted to the absorption properties of the dyes.

In this work, the SDC concept was applied to the N719-based DSSCs in order to improve the photocurrent by adding the dye into the electrolytes. For N719-based DSSCs, the Coumarin 6 (C6) dye was chosen since it has a strong absorption at 444 nm, which is complementary to that of N719, hence improving the light absorption in the trough region. Figure 1 shows the structure of the DSSCs filled with typical electrolyte (S1) and with dye-electrolyte solution (S2).

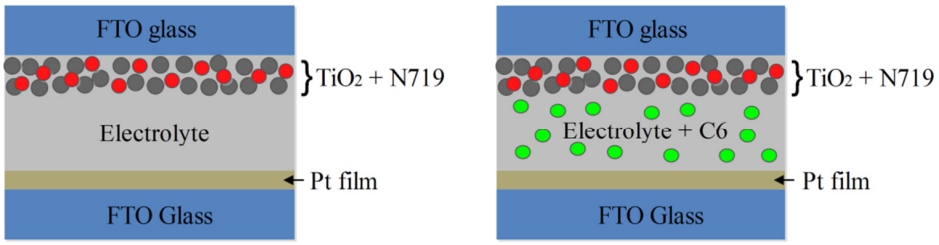

Fig.1. Schematic diagram of the fabricated DSSCs. (A) Sample S1 and (B) Sample S2.

2. Experiment

2.1 Optical properties of Coumarin 6 and N719

The C6 solutions with concentrations ranging from 10-6 to 10-5 M were prepared by dissolving C6 dye in acetonitrile. The absorbance and luminescence spectra of C6 (Sigma-Aldrich) solutions were measured using a UV-Vis spectrometer (Avantes 2048). In the absorption measurement, a 450 W xenon lamp (Edison/FL-1039/40) was used as a light source. The light was guided to the cuvette containing the C6 solution. The transmitted light from the sample was then collected and recorded by the spectrometer. To measure the luminescence spectra, a high power light emitting diode (3 Watt LED) which has a peak emission of 463 nm (Blue) was used as the excitation source. The luminescence light was detected at the right angle to the excitation light source.

2.2 Dye-sensitized solar cells preparation

A screen-printing method was used for a preparation of TiO2 and Pt layers. The screen dimensions were 1.2 mm × 0.3 mm for TiO2 and 0.71 mm × 1.41 mm for Pt with 200 meshes. These layers were coated on the FTO conductive glass (15 Ω/sq, 3 mm thickness from Solaronix) and blow-dried by a hot gun. This coating-drying procedure was repeated until the required thickness is reached. The TiO2 and Pt layers were then sintered at 500 °C for 2 hours. The TiO2 layer was immersed into the N719 in ethanol solution at 60 °C for 1 hour. The working and counter electrodes were assembled into sealed sandwich-type cell by heating with parafilm as a space between the electrodes. It was then filled with electrolyte solution through a drilled hole on the counter electrode and was sealed by using scotch tape cover. In this work, the 0.05 M I2, 0.1 M LiI, 0.4 M 4-tert butylpyridine and 0.06 M PMIMI in acetonitrile with and without C6 dye were used as electrolyte solutions.

The DSSCs were prepared with two different configurations. For ease of explanation, the cells with different structures will be referred as S1 and S2. For the S1 structure, the DSSCs were filled with the electrolyte contained no dye (blank electrolyte). For the S2 structure, the DSSCs were filled with the electrolyte mixed with C6 solution. The concentration of the C6 solution was chosen in such a way that it gave maximum emission spectrum.

2. Results and Discussions

3.1 Optical properties

The absorption and luminescence spectra of C6 solutions are shown in Figures 2-4, respectively. The absorption spectra of the C6 solutions exhibit a typical C6 dye feature, showing a maximum around 440 nm. It is seen that the absorbance increases with dye concentrations whereas the luminescent intensity increases with dye concentrations in a certain range and decreases when the concentration is higher than 5 μM. Comparing the absorption spectra of C6 solution with that of N719 solution, it is seen that the absorption spectrum of C6 lies in the region of 400-500 nm, where the N719 dye exhibits low optical absorption (Fig. 4). These luminescence bands lie in the spectral region 500-600 nm which overlap the absorption band of the N719. Thus, the emitted light could be re-absorbed by the N719 dye.

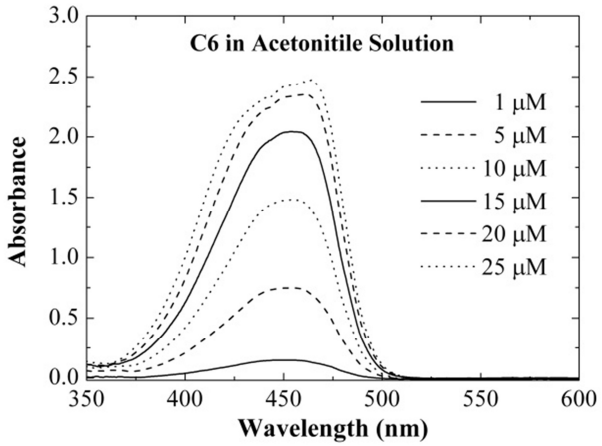

Fig.2. Absorption spectra of C6 solutions with different concentrations.

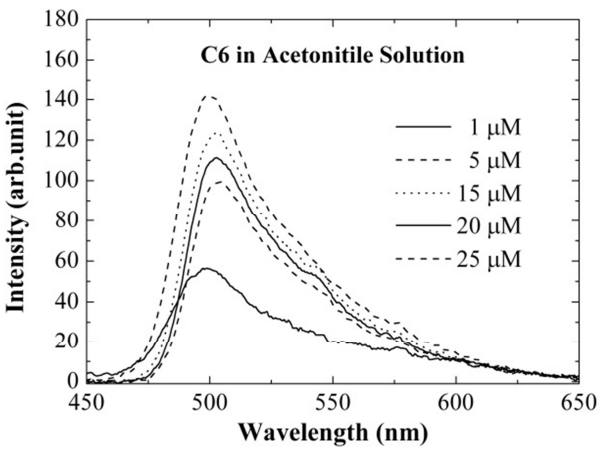

Fig.3. Luminescence spectra of C6 solutions with different concentrations.

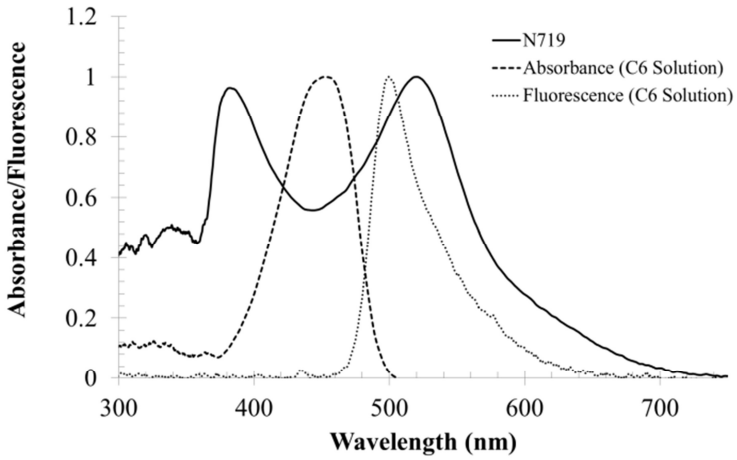

Fig.4. Absorption spectra of N719 and C6 solution and luminescence spectrum of C6 solution.

3.2 Performance comparison of DSSCs

The current density-voltage (J-V) curves of the fabricated DSSCs were measured under simulated light (1 Sun, AM1.5) and the results are shown in Figure 5. The parameters, i.e. short circuit current density (J_{sc}), open circuit voltage (V_{oc}), fill factor (FF), and efficiency (Eff), were extracted from the J-V curves and summarized in Table 1. Comparing the measurement results obtained from the structure S1 and S2 devices, it was found that the J_{sc} of the cells filled with electrolyte contained C6 solution are higher than that of the cells filled with a typical electrolyte solution, by approximately 24.5%. This can be implied that C6 solution can absorb parts of the solar spectrum where N719 has low absorbance and convert them into wavelength better fitted to the absorption spectrum of the N719.

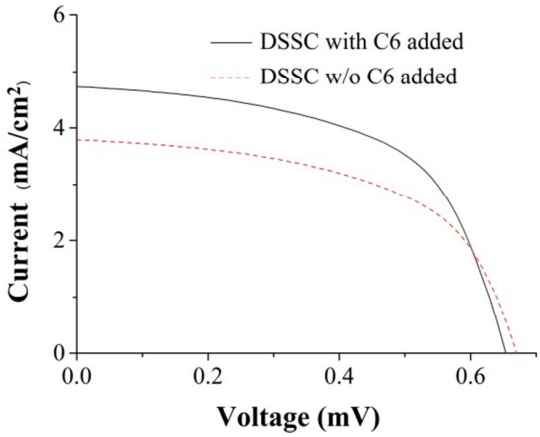

Fig.5. J-V curves of N719 sensitized solar cells with and without C6 added.

Table 1. Performance of DSSCs with different structures

Cell	J_{sc} (mA/cm^2)	V_{oc} (mV)	FF	Eff (%)
S1	3.76	0.67	0.55	1.39
S2	4.68	0.65	0.57	1.76

3. Conclusion

We have investigated the role of Coumarin 6 on the performance of N719 sensitized nanocrystalline TiO_2 solar cells. It was found that by adding C6 into the electrolyte, not only the short circuit current of the DSSCs is improved, but also the fill factor and device efficiency. These results confirm that introducing the C6 into the device structure help improving the photon utilization of the DSSCs.

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